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# ULTRA-HIGH-SPEED RADIOGRAPHIC FILM, IMAGING ASSEMBLY, AND METHOD

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# ULTRA-HIGH-SPEED RADIOGRAPHIC FILM, IMAGING ASSEMBLY, AND METHOD

## FIELD OF THE INVENTION

5        This invention is directed to radiography. In particular, it is directed to an ultra-high speed radiographic silver halide film and imaging assembly that provides improved medical diagnostic images at lower dosage for pediatric radiography. In particular, the invention is useful in the diagnostic evaluation of scoliosis or other conditions requiring low-dosage imaging.

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## BACKGROUND OF THE INVENTION

In conventional medical diagnostic imaging, the object is to obtain an image of a patient's internal anatomy with as little X-radiation exposure as possible. The fastest imaging speeds are realized by mounting a dual-coated

15    radiographic element between a pair of fluorescent intensifying screens for imagewise exposure. About 5% or less of the exposing X-radiation passing through the patient is adsorbed directly by the latent image forming silver halide emulsion layers within the dual-coated radiographic element. Most of the X-radiation that participates in image formation is absorbed by phosphor particles

20    within the fluorescent screens. This stimulates light emission that is more readily absorbed by the silver halide emulsion layers of the radiographic element.

Examples of radiographic element constructions for medical diagnostic purposes are provided by U. S. Patent 4,425,425 (Abbott et al.) and U.S. Patent 4,425,426 (Abbott et al.), U.S. Patent 4,414,310 (Dickerson), U.S.

25    Patent 4,803,150 (Dickerson et al.), U.S. Patent 4,900,652 (Dickerson et al.), U.S. Patent 5,252,442 (Tsaur et al.), U.S. Patent 5,576,156 (Dickerson), and *Research Disclosure*, Vol. 184, August 1979, Item 18431.

### Problem to be Solved

30       Image quality and radiation dosage are two important features of film-screen radiographic combinations (or imaging assemblies). High image quality (that is, high resolution or sharpness) is of course desired, but there is also

the desire to minimize exposure of patients to radiation. Thus, "high speed" radiographic films are needed. However, in known radiographic films, the two features generally go in opposite directions. Thus, films that can be used with low radiation dosages (that is, "high speed" assemblies) generally provide images with

5 poorer image quality (poorer resolution). Lower speed imaging assemblies generally require higher radiation dosages.

Conventional radiographic film-screen combinations, known as imaging assemblies (or systems), useful for general radiography, generally have a total system speed of about 400. The use of higher speed films in such assemblies

10 may not be useful because of a need to control fog or unwanted density in the non-imaged areas of the film.

There is a need for films for pediatric radiography that require minimum radiation dosages with minimal sacrifice in image quality (for example resolution or sharpness).

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## SUMMARY OF THE INVENTION

This invention provides a radiographic imaging assembly that has a system speed of at least 1400 and comprises:

A)      a symmetric radiographic silver halide film having a film

20 speed of at least 900 and comprising a support that has first and second major surfaces and that is capable of transmitting X-radiation,

the radiographic silver halide film having disposed on the first major support surface, one or more hydrophilic colloid layers including a first silver halide emulsion layer, and having on the second major support surface, one

25 or more hydrophilic colloid layers including a second silver halide emulsion layer,

each of the first and second silver halide emulsion layers comprising tabular silver halide grains that have the same or different composition and independently an aspect ratio of at least 35 an average grain diameter of at least 3.0 $\mu$m, and comprise at least 90 mol % bromide and up to 3 mol % iodide,

30 both based on total silver in the grains, and

B)      a fluorescent intensifying screen arranged on each side of the radiographic silver halide film, the screen having a screen speed of at least 600 and a screen sharpness measurement (SSM) value greater than reference Curve A of FIG. 4, and comprising an inorganic phosphor capable of absorbing X-rays and

5      emitting electromagnetic radiation having a wavelength greater than 300 nm, the inorganic phosphor being coated in admixture with a polymeric binder in a phosphor layer onto a flexible support and having a protective overcoat disposed over the phosphor layer.

In preferred embodiments, the present invention provides a

10      radiographic imaging assembly that has a system speed of at least 1400 and comprises:

A)      a symmetric radiographic silver halide film having a film speed of at least 1000 and comprising a support that has first and second major surfaces and that is capable of transmitting X-radiation,

15      the radiographic silver halide film having disposed on the first major support surface, two or more hydrophilic colloid layers including a first silver halide emulsion layer, and having on the second major support surface, two or more hydrophilic colloid layers including a second silver halide emulsion layer,

each of the first and second silver halide emulsion layers

20      comprising tabular silver halide grains that have the same composition, independently an aspect ratio of from about 35 to about 45, an average grain diameter of at least 4.0 $\mu$m, and an average thickness of from about 0.09 to about 0.11 $\mu$m, and comprise at least 98 mol % bromide and up to 0.5 mol % iodide, both based on total silver in the grains,

25      the film further comprising a protective overcoat on both sides of the support disposed over all of the hydrophilic colloid layers,

wherein the tabular silver halide grains in the first and second silver halide emulsion layers are dispersed in a hydrophilic polymeric vehicle mixture comprising from about 0.25 to about 1.5% of deionized oxidized gelatin, based on

30      the total dry weight of the hydrophilic polymeric vehicle mixture, and

B)    a fluorescent intensifying screen having a screen speed of at least 600 and a screen sharpness measurement (SSM) value of at least 1.1 times that of reference Curve A of FIG. 4 at a given spatial frequency, and that comprises a terbium activated gadolinium oxysulfide phosphor capable of

5    absorbing X-rays and emitting electromagnetic radiation having a wavelength greater than 300 nm, the phosphor being coated in admixture with a polymeric binder in a phosphor layer onto a flexible polymeric support and having a protective overcoat disposed over the phosphor layer.

This invention also provides a method of providing a black-and-

10    white image comprising exposing the radiographic silver halide film in a radiographic imaging assembly of the present invention and processing the film, sequentially, with a black-and-white developing composition and a fixing composition, the processing being carried out within 90 seconds, dry-to-dry. The resulting black-and-white images can be used for a medical diagnosis.

15    In particular, the present invention provides high contrast and very sharp images using an imaging assembly that has very high system photographic speed (at least 1400). The resulting images are particularly useful for pediatric radiography where it is particularly desired to limit patient exposure to X-radiation.

20    In addition, all other desirable sensitometric properties are maintained and the radiographic film of the imaging assembly can be rapidly processed in conventional processing equipment and compositions.

These advantages are achieved by using a novel combination of a high speed symmetric radiographic silver halide film and high speed fluorescent

25    intensifying screen. The symmetric radiographic silver halide film has a film speed of at least 900 and has unique silver halide emulsion layers comprising tabular silver halide grains having specific halide compositions, grain sizes, and aspect ratios. In preferred embodiments, the tabular grains of all emulsion layers are dispersed in a hydrophilic polymeric vehicle mixture that includes at least 0.25

30    weight % of oxidized gelatin (based on total dry weight of the hydrophilic polymeric vehicle mixture). With the unique choice of fluorescent intensifying

screen and radiographic film of this invention, images with increased sharpness can be obtained. Such image quality improvements can be characterized by SSM values being greater than the values represented by reference Curve A of FIG. 4 over the range of spatial frequencies.

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## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified schematic representation of a test system used to determine SSM values.

FIG. 2 is a graphical representation of the X-radiation waveform

10    obtained from a typical test system used to determine SSM values.

FIG. 3 is a graphical representation of a Fourier transform of data obtained from repetitions of X-radiation waveforms.

FIG. 4 is a graphical representation of SSM vs. spatial frequencies for the imaging assembly of the present invention described in the Example using

15    Film C and Screen Y.

## DETAILED DESCRIPTION OF THE INVENTION

**Definition of Terms:**

The term "contrast" as herein employed indicates the average

20    contrast derived from a characteristic curve of a radiographic film using as a first reference point (1) a density ($D_1$) of 0.25 above minimum density and as a second reference point (2) a density ($D_2$) of 2.0 above minimum density, where contrast is $\Delta D$ (i.e. 1.75) $\div \Delta \log_{10}E$ ($\log_{10}E_2 - \log_{10}E_1$), $E_1$ and $E_2$ being the exposure levels at the reference points (1) and (2).

25    "Gamma" is described as the instantaneous rate of change of a D logE sensitometric curve or the instantaneous contrast at any logE value.

"System speed" is a measurement given to combinations ("systems" or imaging assemblies) of radiographic silver halide films and fluorescent intensifying screens that is calculated using the conventional ISO

30    9236-1 standard wherein the radiographic film is exposed and processed under the conditions specified in Eastman Kodak Company's Service Bulletin 30. In

general, system speed is thus defined as 1 milliGray/$K_s$ wherein $K_s$ is Air Kerma (in Grays) required to achieve a density = $1.0 + D_{min}$ + fog. In addition, 1 milliRoentgen (mR) is equal to 0.008732 milliGray (mGray). For example, by definition, if 0.1 milliGray (equal to 11.4 mR) incident on a film-screen system creates a density of 1.0 above $D_{min}$ + fog, that film-screen system is considered to have a speed of "10".

However, it is common in the trade to use a "scaled" version of system speed, wherein commercially available KODAK Min-R 2000 radiographic film used in combination with a commercially available KODAK Min-R 2000 intensifying screen is assigned or designated a speed value of "150". Bunch et al. *SPIE Medical Imaging*, Vol. 3659 (1999), pp. 120-130 shows that it requires 6.3 mR for such a KODAK Min-R 2000 film/screen system to reach a density of 1.0 above $D_{min}$ + fog. This gives an ISO speed value of 18.1 for this particular system. Thus, the relationship between the ISO speed value and the common definition of system speed is the ratio 150/18.1 = 8.25. That is, the numerical values of the common system speed values are 8.25 times those directly obtained using equation 7.1 of the noted ISO 9236-1 standard.

The "scaled" system speed values common in the trade are used in this application. However, they can be converted to ISO speed values by dividing them by 8.25.

In this application, "film speed" has been given a standard of "150" for a commercially available KODAK Min-R 2000 radiographic film that has been exposed for 1 second and processed according to the Service Bulletin 30 using a fluorescent intensifying screen containing a terbium activated gadolinium oxysulfide phosphor (such as Screen X noted below in the Example). Thus, if the $K_s$ value for a given system using a given radiographic film is 50% of that for a second film with the same screen and exposure and processing conditions, the first film is considered to have a speed 200% greater than that of the second film. This commercially available film as also been described as Film A in U.S. Patent 6,037,112 (Dickerson).

Also in this application, "screen speed" has been given a standard of "150" for a conventional KODAK Min-R 2000 screen containing a terbium activated gadolinium oxysulfide phosphor. Thus, if the $K_s$ value for a given system using a given screen with a given radiographic film is 50% of that for a

5 second screen with the same film and exposure and processing conditions, the first screen is considered to have a speed 200% greater than that of the second screen. The KODAK Min-R 2000 fluorescent intensifying screen identified above contains a terbium activated gadolinium oxysulfide phosphor (median particle size of about 3.8 to 4.0 μm) and 10 ppm (based on total phosphor weight) of finely

10 divided carbon (0.1 to 0.5 μm) dispersed in a Permuthane U6366™ polyurethane binder on a blue-tinted poly(ethylene terephthalate) film support having a thickness of about 180 μm. The total phosphor coverage is 3.3 $g/dm^2$ and the phosphor to binder weight ratio is 21:1. The dried thickness of the phosphor layer is about 84 μm phosphor to binder weight ratio is 21:1. The dried thickness of the

15 phosphor layer is about 84 μm. Over the phosphor layer is disposed a protective overcoat layer comprising cellulose acetate and crosslinked polystyrene matte particles present at 3% of the weight of the total overcoat. The overcoat has been coated to a dry thickness of about 6 μm.

The "screen sharpness measurement" (SSM) described herein is a

20 parameter that has been found to correlate well with visual appearance of image sharpness if other conditions are held constant.

Each screen sharpness measurement described in this application was made using a test system that is described as follows as illustrated in FIG. 1. A slit-shaped X-ray exposure 10 was made onto phosphor screen sample 15 (in a

25 front-screen configuration) that was in contact with optical slit 20. The profile or spread 45 of the emitted light from the screen was determined by scanning optical slit 20 relative to X-ray slit (or mask) 25 and digitizing the resulting signal. Photomultiplier tube 30 (PMT) was used to detect the light that passed through optical slit 20. Data processing was done during acquisition and analysis to

30 minimize noise in the resulting light spread profile (LSP). A Fourier transform of the LSP was calculated to give the SSM as a function of spatial frequency.

In FIG. 1, a very narrow tungsten carbide mask (10-15 μm wide, about 0.64 cm thick, and about 0.64 cm long) was used as X-ray slit **25** to provide slit-shaped X-ray exposure **10**. X-ray slit **25** was held fixed with respect to the source of X-radiation. Phosphor screen sample **15** was placed face down (exit

5      surface) on top of optical slit **20** made of two pieces of sharpened tool steel. The steel had been darkened by a chemical treatment and further blackened by a black felt-tipped pen. Phosphor screen sample **15** was held in place by a piece of a carbon fiber cassette panel (not shown) that was held down by pressure from spring-loaded plungers (not shown). The light passed through optical slit **20** was

10     collected by integrating sphere **35** and a fraction of it was then detected by PMT **30**. The whole assembly of phosphor screen sample **15**, optical slit **20**, integrating sphere **35**, and PMT **30** was translated relative to X-ray slit **25**. Optical slit **20** was aligned with X-ray slit **25**. As phosphor screen sample **15** was passed under X-ray slit **25**, the light that passed through optical slit **20** varied according to the profile

15     of lateral light spread within phosphor screen sample **15**.

Any suitable source of X-radiation can be used for this test. To obtain the data described in this application, the X-radiation source was a commercially available Torrex 120D X-Ray Inspection System. Inside this system, the linear translation table that holds the entire assembly was under

20     computer control (any suitable computer can be used). Integrating sphere **35** had a 4-inch (10.2 cm) diameter and was appropriately reflective. One such integrating sphere can be obtained from Labsphere. The top port of integrating sphere **35** that accepted the light from optical slit **20** was 1 inch (2.54 cm) in diameter. The side port that was used for PMT **30** was also 1 inch (2.54 cm) in diameter. While any

25     suitable PMT can be used, we used a Hamamatsu 81925 with a quartz window for extended UV response. It was about 1 inch (2.54 cm) in diameter, and had a very compact dynode chain so the length of the PMT was minimized. High voltage was supplied to PMT **30** by a 0-1kV power supply (not shown). A transimpedence amplifier (not shown) having a simple single RC bandwidth

30     limitation of around 1 kHz was constructed. The signal from PMT **30** was low-pass filtered using a 24dB/octave active filter set at a bandwidth of about 300

Hertz. A suitable computer system (for example, an Intel 486DX-33MHz DOS computer system) was used for data acquisition and analysis. The X-radiation source was slightly modified to allow for computer control and monitoring of the unit by the computer. Two digital output lines were used for START and STOP

5    of the X-ray tube current, and one digital input line was used to monitor the XRAY ON signal to assure that the unit was indeed on.

LSP was measured in the following manner. The optical slit/integrating sphere/PMT assembly was moved relative to X-ray slit **25**. The X-radiation generation unit generated X-rays such that the intensity followed a 60 Hz

10   single-wave rectified waveform in time as shown in FIG. 2. To take advantage of this, a single data point that represents the value of the LSP at a given spatial position was generated by acquiring an array of data at each spatial position using time intervals between points in this temporal array small enough such that the X-ray intensity waveform can be adequately represented by this array of data.

15   Several repetitions of the waveform were captured in one array of data. A Fourier transform of this array of data yielded an array of data giving the amplitude of signal at various temporal frequencies that looked like that shown in FIG. 3. After the transform was done, the integral (sum) under the 60 and 120 Hz peaks was used as the value of the LSP at the current spatial position.

20   When the phosphor screen sample had been placed in the X-radiation generating unit, and the computer program for acquisition has been initiated, the program first set the proper high voltage to the PMT. This allows phosphor screens having various brightnesses to be tested. After the computer had turned on the X-radiation generating unit, but prior to beginning the actual LSP

25   data acquisition, the computer performed a brief data acquisition near the peak region of the LSP so that it can find the actual peak. The computer then positions the translation stage at this peak signal position and adjusted the PMT high voltage to provide peak signal between 1/2 and full scale of the analog-to-digital converter range. The translation stage was then moved 500 positions away from

30   the peak and data acquisition is begun.

There are 1000 spatial positions, each separated by 10 m$\mu$, at which the value of the LSP was determined. The peak of the LSP was approximated at data point 500. Given that the majority of the LSP data acquired represent baseline, for the first 400 values of the LSP and the last 400 values of the LSP,

5    fewer actual data points were acquired, and the intermediate points (between the actual points) were determined by simple linear interpolation. For each actual data point in these "baseline" regions, the temporal data array was long enough to capture eight repetitions of the single wave rectified X-ray generator waveform. In an effort to minimize errors on the baseline from current bursts in the PMT, a

10   running average value for the baseline was determined and the next data point must fall within some predetermined range of that running average or the acquisition is repeated. For LSP data values 401-600, a data point was acquired at each spatial position. To improve the signal-to-noise in this portion of the LSP, effectively 32 repetitions of the waveform were captured (the average of 4

15   repeats of the 8 waveform acquisition). At the completion of the acquisition, the PMT high voltage was reduced to zero, the X-radiation generating unit was turned off, and the stage was positioned approximately at data point 500 (the peak of the LSP).

Substantial smoothing of the baseline of the data array was done to

20   aid in subsequent analysis. A mirror analysis was done to assure symmetry to the LSP. This mirror analysis consists of varying the midpoint for the LSP array by amounts less than a full data point spacing, re-sampling the array by interpolation, then calculating the difference between points at mirror positions relative to a given midpoint. The value of the midpoint that gives the minimum difference

25   between left and right is the optimal midpoint. The LSP array was then forced to be symmetric by placing the average value of two mirror points in place of the actual data value for each point in a mirror set. The value of the LSP at the peak position was determined by fitting a parabola to the two points on either side of, the peak position.

30   After this mirror analysis was completed, the baseline was subtracted. The baseline value removed was determined by averaging values at

the beginning and the end of the data array. To eliminate noise in the resulting SSM caused by noise in the baseline data, the baseline data were replaced with an extrapolation of the LSP by fitting an exponential function (least squares method) to the LSP data from 4% down to 1% of the peak value. Then, a Hanning window

5  was applied to the data:

$$(x_n' = x_n [0.5(1 - \cos(2\pi n / 1000))]) .$$

Finally, the Fourier transform of the LSP was computed. The equation used for this transformation is

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$$X_k = \frac{1}{N} \sum_{n=0}^{N-1} x_n \, e^{-2\pi i (\frac{nk}{N})}$$

wherein $X_k$ represents the modulation at frequency k, and $x_n$ is the measured LSP at spatial positions n. By the properties of the discrete Fourier Transform, the combination of 1000 data points at a spacing of 10 m$\mu$ yielded an array of data

15  after the Fourier Transform that are spaced every 0.1 cycles/mm. The modulation array was normalized to a value of 1.0 at zero spatial frequency. This modulation data gave a measure of the screen sharpness, i.e. the higher the modulation (closer to 1) at higher spatial frequencies, the sharper the image that the phosphor screen can produce. The value of the modulation at selected spatial frequencies is the

20  "Screen Sharpness Measurement" (SSM).

For example, the fluorescent intensifying screens used in the practice of this invention are capable of providing SSM values greater than those represented by reference Curve A of FIG. 4 over the spatial frequency range of from 0 to 10 cycles/mm. TABLE I below lists selected SSM vs. spatial frequency

25  data from which FIG. 4 was generated. Preferred screens used in the practice of this invention are those having SSM values that are at least 1.1 times those represented by reference Curve A of FIG. 4 over a range a spatial frequency range of from 1 to 10 cycles/mm.

TABLE I

| SSM | Spatial Frequency (cycles/mm) |
|---|---|
| 1.000 | 0 |
| 0.821 | 0.5 |
| 0.547 | 1.0 |
| 0.357 | 1.5 |
| 0.240 | 2.0 |
| 0.165 | 2.5 |
| 0.118 | 3.0 |
| 0.087 | 3.5 |
| 0.066 | 4.0 |
| 0.053 | 4.5 |
| 0.044 | 5.0 |
| 0.038 | 5.5 |
| 0.032 | 6.0 |
| 0.028 | 6.5 |
| 0.024 | 7.0 |
| 0.020 | 7.5 |
| 0.017 | 8.0 |
| 0.015 | 8.5 |
| 0.013 | 9.0 |
| 0.011 | 9.5 |
| 0.010 | 10.0 |

The term "dual-coated" is used to define a radiographic film having silver halide emulsion layers disposed on both the front- and backsides of the support. The radiographic silver halide films useful in the present invention are "dual-coated."

The radiographic films useful in the present invention are "symmetric" films. Wherein the silver halide emulsion layers on each side of the

support are essentially the same (no compositional differences that provide significant coating or imaging differences).

The term "rapid access processing" is employed to indicate dry-to-dry processing of a radiographic film in 45 seconds or less. That is, 45 seconds or

5 less elapse from the time a dry imagewise exposed radiographic film enters a wet processor until it emerges as a dry fully processed film.

In referring to grains and silver halide emulsions containing two or more halides, the halides are named in order of ascending molar concentrations.

10 The term "equivalent circular diameter" (ECD) is used to define the diameter of a circle having the same projected area as a silver halide grain. This can be measured using known techniques.

The term "aspect ratio" is used to define the ratio of grain ECD to grain thickness.

15 The term "coefficient of variation" (COV) is defined as 100 times the standard deviation (a) of grain ECD divided by the mean grain ECD.

The term "fluorescent intensifying screen" refers to a screen that absorbs X-radiation and emits light. A "prompt" emitting fluorescent intensifying screen will emit light immediately upon exposure to radiation while "storage"

20 fluorescent screen can "store" the exposing X-radiation for emission at a later time when the screen is irradiated with other radiation (usually visible light).

The terms "front" and "back" refer to layers, films, or fluorescent intensifying screens nearer to and farther from, respectively, the source of X-radiation.

25 *Research Disclosure* is published by Kenneth Mason Publications, Ltd., Dudley House, 12 North St., Emsworth, Hampshire PO10 7DQ England. The publication is also available from Emsworth Design Inc., 147 West 24th Street, New York, N.Y. 10011.

**Radiographic Films**

The radiographic silver halide films useful in this invention include a flexible support having disposed on both sides thereof, one or more photographic silver halide emulsion (hydrophilic colloid) layers and optionally

5 one or more non-radiation sensitive hydrophilic colloid layer(s). Thus, the "first" silver halide emulsion layer is considered to be disposed on the frontside of the support and the "second" silver halide emulsion layer is considered to be disposed on the backside of the support. The first and second silver halide emulsion layers can be the same or different in composition.

10 In preferred embodiments, the radiographic silver halide films have the same, single silver halide emulsion layer on each side of the support and a protective overcoat (described below) over all layers on each side of the support. Thus, in these preferred embodiments, the first and second silver halide emulsion layers have essentially the same composition (for example,

15 components, types of grains, silver halide composition, hydrophilic colloid binder composition, $g/m^2$ coverage).

The support can take the form of any conventional radiographic film support that is X-radiation and light transmissive. Useful supports for the films of this invention can be chosen from among those described in *Research*

20 *Disclosure*, September 1996, Item 38957 XV. Supports and *Research Disclosure*, Vol. 184, August 1979, Item 18431, XII. Film Supports. The support is preferably a transparent film support. In its simplest possible form the transparent film support consists of a transparent film chosen to allow direct adhesion of the hydrophilic silver halide emulsion layers or other hydrophilic layers. More

25 commonly, the transparent film is itself hydrophobic and subbing layers are coated on the film to facilitate adhesion of the hydrophilic silver halide emulsion layers. Typically the film support is either colorless or blue tinted (tinting dye being present in one or both of the support film and the subbing layers). Polyethylene terephthalate and polyethylene naphthalate are the preferred transparent film

30 support materials.

In the more preferred embodiments, at least one non-light sensitive hydrophilic layer is included with the silver halide emulsion layer on each side of the film support. This layer may be an interlayer or overcoat, or both types of non-light sensitive layers can be present.

5          The first and second silver halide emulsion layers comprise predominantly (more than 50%, and preferably at least 70%, of the total grain projected area) tabular silver halide grains. The grain composition can vary between the layers, but preferably, the grain composition is essentially the same in the silver halide emulsion layers. These tabular silver halide grains generally

10        comprise at least 90, preferably at least 95, and more preferably at least 98, mol % bromide, based on total silver in the emulsion layer. Such emulsions include silver halide grains composed of, for example, silver iodobromide, silver chlorobromide, silver iodochlorobromide, and silver chloroiodobromide. The iodide grain content is generally up to 3 mol %, based on total silver in the

15        emulsion layer. Preferably the iodide grain content is up to 2 mol %, and more preferably up to about 0.5 mol % (based on total silver in the emulsion layer). Mixtures of different tabular silver halide grains can be used in either of the silver halide emulsion layers.

          Either silver halide emulsion layer can also include some non-

20        tabular silver halide grains having any desirable non-tabular morphology or be comprised of a mixture of two or more of such morphologies. The composition and methods of making such silver halide grains are well known in the art.

          The tabular silver halide grains used in the first and second silver halide emulsion layers generally have as aspect ratio of 35 or more, and preferably

25        from about 35 to about 45. The aspect ratio can be the same or different in the two silver halide emulsion layers. Preferably, the aspect ratio is essentially the same in both layers.

          In general, the tabular grains in any of the silver halide emulsion layers have an average grain diameter (ECD) of at least 3.0 μm, and preferably of

30        at least 4.0 μm. The average grain diameters can be the same or different in the

various emulsion layers.  At least 100 non-overlapping tabular grains are measured to obtain the "average" ECD.

In addition, the tabular grains in the first and second silver halide emulsion layers generally have an average thickness of from about 0.08 to about 0.12 μm, and preferably from about 0.09 to about 0.11 μm.  The average thickness can be the same or different but preferably it is essentially the same for both layers.

The procedures and equipment used to determine tabular grain size (and aspect ratio) are well known in the art.

Tabular grain emulsions that have the desired composition and sizes are described in greater detail in the following patents, the disclosures of which are incorporated herein by reference:

U. S. Patent 4,414,310 (Dickerson), U.S. Patent 4,425,425 (Abbott et al.), U.S. Patent 4,425,426 (Abbott et al.), U.S. Patent 4,439,520 (Kofron et al.), U.S. Patent 4,434,226 (Wilgus et al.), U.S. Patent 4,435,501 (Maskasky), U.S. Patent 4,713,320 (Maskasky), U.S. Patent 4,803,150 (Dickerson et al.), U.S. Patent 4,900,355 (Dickerson et al.), U.S. Patent 4,994,355 (Dickerson et al.), U.S. Patent 4,997,750 (Dickerson et al.), U.S. Patent 5,021,327 (Bunch et al.), U.S. Patent 5,147,771 (Tsaur et al.), U.S. Patent 5,147,772 (Tsaur et al.), U.S. Patent 5,147,773 (Tsaur et al.), U.S. Patent 5,171,659 (Tsaur et al.), U.S. Patent 5,252,442 (Dickerson et al.), U.S. Patent 5,370,977 (Zietlow), U.S. Patent 5,391,469 (Dickerson), U.S. Patent 5,399,470 (Dickerson et al.), U.S. Patent 5,411,853 (Maskasky), U.S. Patent 5,418,125 (Maskasky), U.S. Patent 5,494,789 (Daubendiek et al.), U.S. Patent 5,503,970 (Olm et al.), U.S. Patent 5,536,632 (Wen et al.), U.S. Patent 5,518,872 (King et al.), U.S. Patent 5,567,580 (Fenton et al.), U.S. Patent 5,573,902 (Daubendiek et al.), U.S. Patent 5,576,156 (Dickerson), U.S. Patent 5,576,168 (Daubendiek et al.), U.S. Patent 5,576,171 (Olm et al.), and U.S. Patent 5,582,965 (Deaton et al.).

The silver halide emulsion layers on opposite sides of the support can have the same or different dry unprocessed thickness and coating weight, but

preferably, the two silver halide emulsion layers have the same dry thickness and coating weight.

Unlike many other radiographic silver halide films known in the art, the radiographic silver halide films useful in this invention do not contain

5 what are known as "crossover control agents". This means that such agents are not intentionally included in or incorporated into the films but it is understood that some other components of the films (for example, tabular silver halide grains) may inherently reduce crossover to some extent.

A variety of silver halide dopants can be used, individually and in

10 combination, in one or more of the silver halide emulsion layers to improve contrast as well as other common sensitometric properties. A summary of conventional dopants is provided by *Research Disclosure*, Item 38957, cited above, Section I. Emulsion grains and their preparation, sub-section D. Grain modifying conditions and adjustments, paragraphs (3), (4), and (5).

15 A general summary of silver halide emulsions and their preparation is provided by *Research Disclosure*, Item 38957, cited above, Section I. Emulsion grains and their preparation. After precipitation and before chemical sensitization the emulsions can be washed by any convenient conventional technique using techniques disclosed by *Research Disclosure*, Item 38957, cited above, Section III.

20 Emulsion washing.

Any of the emulsions can be chemically sensitized by any convenient conventional technique as illustrated by *Research Disclosure*, Item 38957, Section IV. Chemical Sensitization: Sulfur, selenium or gold sensitization (or any combination thereof) is specifically contemplated. Sulfur sensitization is

25 preferred, and can be carried out using for example, thiosulfates, thiosulfonates, thiocyanates, isothiocyanates, thioethers, thioureas, cysteine, or rhodanine. A combination of gold and sulfur sensitization is most preferred.

In addition, if desired, any of the silver halide emulsions can include one or more suitable spectral sensitizing dyes that include, for example,

30 cyanine and merocyanine spectral sensitizing dyes. The useful amounts of such dyes are well known in the art but are generally within the range of from about

200 to about 1000 mg/mole of silver in the given emulsion layer. It is particularly preferred that all of the tabular silver halide grains used in the present invention (in all silver halide emulsion layers) be "green-sensitized", that is spectrally sensitized to radiation of from about 470 to about 570 nm of the electromagnetic

5      spectrum. Various spectral sensitizing dyes are known for achieving this characteristic.

Instability that increases minimum density in negative-type emulsion coatings (that is fog) can be protected against by incorporation of stabilizers, antifoggants, antikinking agents, latent-image stabilizers and similar

10     addenda in the emulsion and contiguous layers prior to coating. Such addenda are illustrated by *Research Disclosure*, Item 38957, Section VII. Antifoggants and stabilizers, and Item 18431, Section II: Emulsion Stabilizers, Antifoggants and Antikinking Agents.

It may also be desirable that one or more silver halide emulsion

15     layers include one or more covering power enhancing compounds adsorbed to surfaces of the silver halide grains. A number of such materials are known in the art, but preferred covering power enhancing compounds contain at least one divalent sulfur atom that can take the form of a -S- or =S moiety. Such compounds are described in U.S. Patent 5,800,976 (Dickerson et al.) that is

20     incorporated herein by reference for the teaching of such sulfur-containing covering power enhancing compounds.

The silver halide emulsion layers and other hydrophilic layers on both sides of the support of the radiographic films of this invention generally contain conventional polymer vehicles (peptizers and binders) that include both

25     synthetically prepared and naturally occurring colloids or polymers. The most preferred polymer vehicles include gelatin or gelatin derivatives alone or in combination with other vehicles. Conventional gelatino-vehicles and related layer features are disclosed in *Research Disclosure*, Item 38957, Section II. Vehicles, vehicle extenders, vehicle-like addenda and vehicle related addenda. The

30     emulsions themselves can contain peptizers of the type set out in Section II, paragraph A. Gelatin and hydrophilic colloid peptizers. The hydrophilic colloid

peptizers are also useful as binders and hence are commonly present in much
higher concentrations than required to perform the peptizing function alone. The
preferred gelatin vehicles include alkali-treated gelatin, acid-treated gelatin or
gelatin derivatives (such as acetylated gelatin, deionized gelatin, oxidized gelatin

5    and phthalated gelatin). Cationic starch used as a peptizer for tabular grains is
described in U.S. Patent 5,620,840 (Maskasky) and U.S. Patent 5,667,955
(Maskasky). Both hydrophobic and hydrophilic synthetic polymeric vehicles can
be used also. Such materials include, but are not limited to, polyacrylates
(including polymethacrylates), polystyrenes and polyacrylamides (including

10   polymethacrylamides). Dextrans can also be used. Examples of such materials
are described for example in U.S. Patent 5,876,913 (Dickerson et al.),
incorporated herein by reference.

          Thin, high aspect ratio tabular grain silver halide emulsions useful
in the present invention will typically be prepared by processes including

15   nucleation and subsequent growth steps. During nucleation, silver and halide salt
solutions are combined to precipitate a population of silver halide nuclei in a
reaction vessel. Double jet (addition of silver and halide salt solutions
simultaneously) and single jet (addition of one salt solution, such as a silver salt
solution, to a vessel already containing an excess of the other salt) process are

20   known. During the subsequent growth step, silver and halide salt solutions,
and/or preformed fine silver halide grains, are added to the nuclei in the reaction
vessel, and the added silver and halide combines with the existing population of
grain nuclei to form larger grains. Control of conditions for formation of high
aspect ratio tabular grain silver bromide and iodobromide emulsions is known,

25   e.g., based upon (Wilgus et al.) U.S. Patent No. 4,434,226, (Solberg et al.) U.S.
Patent No. 4,433, 048 and (Kofron et al.) U.S. Patent No. 4,439,520. It is
recognized, e.g., that the bromide ion concentration in solution at the stage of
grain formation must be maintained within limits to achieve the desired tabularity
of grains. As grain growth continues, the bromide ion concentration in solution

30   becomes progressively less influential on the grain shape ultimately achieved. For
example, Wilgus et al U.S. Patent No. 4,434,226, e.g., teaches the precipitation of

high aspect ratio tabular grain silver bromoiodide emulsions at bromide ion concentrations in the pBr range of from 0.6 to 1.6 during grain nucleation, with the pBr range being expanded to 0.6 to 2.2 during subsequent grain growth. (Kofron et al.) U.S. Patent No. 4,439,520 extends these teachings to the precipitation of

5    high aspect ratio tabular grain silver bromide emulsions. pBr is defined as the negative log of the solution bromide ion concentration. (Daubendiek et al.) U.S. Patent No. 4,414,310 describes a process for the preparation of high aspect ratio silver bromoiodide emulsions under pBr conditions not exceeding the value of 1.64 during grain nucleation. (Maskasky) U.S. Pat. No. 4,713,320 in the

10   preparation of high aspect ratio silver halide emulsions, teaches that the useful pBr range during nucleation can be extended to a value of 2.4 when the precipitation of the tabular silver bromide or bromoiodide grains occurs in the presence of gelatino-peptizer containing less than 30 micromoles of methionine (e.g., oxidized gelatin) per gram. The use of such oxidized gel also enables the preparation of

15   thinner and/or larger diameter grains, and/or more uniform grain populations containing fewer non-tabular grains.

The use of oxidized gelatin as peptizer during nucleation, such as taught by U.S. Patent No. 4,713,320, is particularly preferred for making thin, high aspect ratio tabular grain emulsions for use in the present invention, employing

20   either double or single jet nucleation processes. As gelatin employed as peptizer during nucleation typically will comprise only a fraction of the total gelatin employed in an emulsion, the percentage of oxidized gelatin in the resulting emulsion may be relatively small, that is, at least 0.25% (based on total dry weight).

25   Thus it is preferred that the coated first and second tabular grain silver halide emulsion layers comprise tabular silver halide grains dispersed in a hydrophilic polymeric vehicle mixture comprising at least 0.25% and preferably at least 0.35% of oxidized gelatin based on the total dry weight of hydrophilic polymeric vehicle mixture in that coated emulsion layer. The upper limit for the

30   oxidized gelatin is not critical but for practical purposes it is 1.5% based on the total dry weight of the hydrophilic polymer vehicle mixture. Preferably, from

about 0.4 to about 0.6% (by dry weight) of the hydrophilic polymer vehicle mixture is oxidized gelatin.

It is also preferred that the oxidized gelatin be in the form of deionized oxidized gelatin but non-deionized oxidized gelatin can be used, or a mixture of deionized and non-deionized oxidized gelatins can be used. Deionized or non-deionized oxidized gelatin generally has the property of relatively lower amounts of methionine per gram of gelatin than other forms of gelatin. Preferably, the amount of methionine is from 0 to about 3 µmol of methionine, and more preferably from 0 to 1 µmol of methionine, per gram of gelatin. This material can be prepared using known procedures.

The remainder of the polymeric vehicle mixture can be any of the hydrophilic vehicles described above, but preferably it is composed of alkali-treated gelatin, acid-treated gelatin acetylated gelatin, or phthalated gelatin.

The silver halide emulsions containing the tabular silver halide grains described above can be prepared as noted using a considerable amount of oxidized gelatin (preferably deionized oxidized gelatin) during grain nucleation and growth, and then additional polymeric binder can be added to provide the coating formulation. The amounts of oxidized gelatin in the emulsion can be as low as 0.3 g per mole of silver and as high as 27 g per mole of silver in the emulsion. Preferably, the amount of oxidized gelatin in the emulsion is from about 1 to about 20 g per mole of silver.

The silver halide emulsion layers (and other hydrophilic layers) in the radiographic films are generally fully hardened using one or more conventional hardeners. Thus, the amount of hardener on each side of the support is generally at least 1.5% and preferably at least 2.5%, based on the total dry weight of the polymer vehicles on each side of the support.

The levels of silver and polymer vehicle in the radiographic silver halide film of the present invention can vary in the various silver halide emulsion layers. In general, the total amount of silver on each side of the support is at least 18 and no more than 24 $mg/dm^2$ (preferably from about 18 to about 20 $mg/dm^2$). In addition, the total coverage of polymer vehicle on each side of the support is

generally at least 30 and no more than 40 mg/dm$^2$ (preferably from about 32 to about 35 mg/dm$^2$). The amounts of silver and polymer vehicle on the two sides of the support in the radiographic silver halide film can be the same or different. These amounts refer to dry weights.

5       The radiographic silver halide films of this invention generally include a surface protective overcoat disposed on each side of the support that typically provides for physical protection of the various layers underneath. Each protective overcoat can be sub-divided into two or more individual layers. For example, protective overcoats can be sub-divided into surface overcoats and

10       interlayers (between the overcoat and silver halide emulsion layers). In addition to vehicle features discussed above the protective overcoats can contain various addenda to modify the physical properties of the overcoats. Such addenda are illustrated by *Research Disclosure*, Item 38957, Section IX. Coating physical property modifying addenda, A. Coating aids, B. Plasticizers and lubricants, C.

15       Antistats, and D. Matting agents. Interlayers that are typically thin hydrophilic colloid layers can be used to provide a separation between the silver halide emulsion layers and the surface overcoats or between the silver halide emulsion layers. The overcoat on at least one side of the support can also include a blue toning dye or a tetraazaindene (such as 4-hydroxy-6-methyl-1,3,3a,7-

20       tetraazaindene) if desired.

      The protective overcoat is generally comprised of one or more hydrophilic colloid vehicles, chosen from among the same types disclosed above in connection with the emulsion layers.

      The various coated layers of radiographic silver halide films of this

25       invention can also contain tinting dyes to modify the image tone to transmitted or reflected light. These dyes are not decolorized during processing and may be homogeneously or heterogeneously dispersed in the various layers. Preferably, such non-bleachable tinting dyes are in a silver halide emulsion layer.

**Imaging Assemblies**

The radiographic imaging assemblies of the present invention are composed of one radiographic silver halide film as described herein and one or more fluorescent intensifying screens to provide a cumulative system speed of at

5    least 1400 for the entire imaging assembly. The film and one or more screens are generally arranged in a suitable "cassette" designed for this purpose. Usually, two fluorescent intensifying screens are used, one of the "frontside" and the other on the "backside" of the film. Fluorescent intensifying screens are typically designed to absorb X-rays and to emit electromagnetic radiation having a wavelength

10    greater than 300 nm. These screens can take any convenient form providing they meet all of the usual requirements for use in radiographic imaging. Examples of conventional, useful fluorescent intensifying screens and methods of making them are provided by *Research Disclosure*, Item 18431, cited above, Section IX. X-Ray Screens/Phosphors, and U.S. Patent 5,021,327 (Bunch et al.), U.S. Patent

15    4,994,355 (Dickerson et al.), U.S. Patent 4,997,750 (Dickerson et al.), and U.S. Patent 5,108,881 (Dickerson et al.), the disclosures of which are here incorporated by reference. The fluorescent layer contains phosphor particles and a binder, optimally additionally containing a light scattering material, such as titania.

Any conventional or useful phosphor can be used, singly or in

20    mixtures, in the intensifying screens used in the practice of this invention. For example, useful phosphors are described in numerous references relating to fluorescent intensifying screens, including but not limited to, *Research Disclosure*, Vol. 184, August 1979, Item 18431, Section IX, X-ray Screens/Phosphors, and U.S. Patent 2,303,942 (Wynd et al.), U.S. Patent 3,778,615 (Luckey), U.S. Patent

25    4,032,471 (Luckey), U.S. Patent 4,225,653 (Brixner et al.), U.S. Patent 3,418,246 (Royce), U.S. Patent 3,428,247 (Yocon), U.S. Patent 3,725,704 (Buchanan et al.), U.S. Patent 2,725,704 (Swindells), U.S. Patent 3,617,743 (Rabatin), U.S. Patent 3,974,389 (Ferri et al.), U.S. Patent 3,591,516 (Rabatin), U.S. Patent 3,607,770 (Rabatin), U.S. Patent 3,666,676 (Rabatin), U.S. Patent 3,795,814 (Rabatin), U.S.

30    Patent 4,405,691 (Yale), U.S. Patent 4,311,487 (Luckey et al.), U.S. Patent 4,387,141 (Patten), U.S. Patent 5,021,327 (Bunch et al.), U.S. Patent 4,865,944

(Roberts et al.), U.S. Patent 4,994,355 (Dickerson et al.), U.S. Patent 4,997,750 (Dickerson et al.), U.S. Patent 5,064,729 (Zegarski), U.S. Patent 5,108,881 (Dickerson et al.), U.S. Patent 5,250,366 (Nakajima et al.), U.S. Patent 5,871,892 (Dickerson et al.), EP 0 491,116A1 (Benzo et al.), the disclosures of all of which

5    are incorporated herein by reference with respect to the phosphors.

For example, the inorganic phosphor can be calcium tungstate, activated or unactivated lithium stannates, niobium and/or rare earth activated or unactivated yttrium, lutetium, or gadolinium tantalates, rare earth (such as terbium, lanthanum, gadolinium, cerium, and lutetium)-activated or unactivated

10   middle chalcogen phosphors such as rare earth oxychalcogenides and oxyhalides, and terbium-activated or unactivated lanthanum and lutetium middle chalcogen phosphors.

Still other useful phosphors are those containing hafnium as described for example in U.S. Patent 4,988,880 (Bryan et al.), U.S. Patent

15   4,988,881 (Bryan et al.), U.S. Patent 4,994,205 (Bryan et al.), U.S. Patent 5,095,218 (Bryan et al.), U.S. Patent 5,112,700 (Lambert et al.), U.S. Patent 5,124,072 (Dole et al.), and U.S. Patent 5,336,893 (Smith et al.), the disclosures of which are all incorporated herein by reference.

Alternatively, the inorganic phosphor is a rare earth

20   oxychalcogenide and oxyhalide phosphors are represented by the following formula (1):

$$M'_{(w-n)}M''_nO_wX' \qquad (1)$$
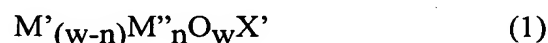
wherein M' is at least one of the metals yttrium (Y), lanthanum (La), gadolinium (Gd), or lutetium (Lu), M'' is at least one of the rare earth metals, preferably

25   dysprosium (Dy), erbium (Er), europium (Eu), holmium (Ho), neodymium (Nd), praseodymium (Pr), samarium (Sm), tantalum (Ta), terbium (Tb), thulium (Tm), or ytterbium (Yb), X' is a middle chalcogen (S, Se, or Te) or halogen, n is 0.002 to 0.2, and w is 1 when X' is halogen or 2 when X' is a middle chalcogen. These include rare earth-activated lanthanum oxybromides, and terbium-activated or

30   thulium-activated gadolinium oxides or oxysulfides (such as $Gd_2O_2S:Tb$).

Other suitable phosphors are described in U.S. Patent 4,835,397 (Arakawa et al.) and U.S. Patent 5,381,015 (Dooms), both incorporated herein by reference, and including for example divalent europium and other rare earth activated alkaline earth metal halide phosphors and rare earth element activated

5     rare earth oxyhalide phosphors. Of these types of phosphors, the more preferred phosphors include alkaline earth metal fluorohalide prompt emitting and/or storage phosphors [particularly those containing iodide such as alkaline earth metal fluorobromoiodide storage phosphors as described in U.S. Patent 5,464,568 (Bringley et al.), incorporated herein by reference].

10              Another class of useful phosphors includes rare earth hosts such as rare earth activated mixed alkaline earth metal sulfates such as europium-activated barium strontium sulfate.

Particularly useful phosphors are those containing doped or undoped tantalum such as $YTaO_4$, $YTaO_4$:Nb, $Y(Sr)TaO_4$, and $Y(Sr)TaO_4$:Nb.

15     These phosphors are described in U.S. Patent 4,226,653 (Brixner), U.S. Patent 5,064,729 (Zegarski), U.S. Patent 5,250,366 (Nakajima et al.), and U.S. Patent 5,626,957 (Benso et al.), all incorporated herein by reference.

Other useful phosphors are alkaline earth metal phosphors that can be the products of firing starting materials comprising optional oxide and a

20     combination of species characterized by the following formula (2):

$$MFX_{1-z}I_zuM^aX^a{:}yA{:}eQ{:}tD \qquad (2)$$
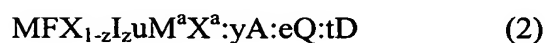
wherein "M" is magnesium (Mg), calcium (Ca), strontium (Sr), or barium (Ba), "F" is fluoride, "X" is chloride (Cl) or bromide (Br), "I" is iodide, $M^a$ is sodium (Na), potassium (K), rubidium (Rb), or cesium (Cs), $X^a$ is fluoride (F), chloride

25     (Cl), bromide (Br), or iodide (I), "A" is europium (Eu), cerium (Ce), samarium (Sm), or terbium (Tb), "Q" is BeO, MgO, CaO, SrO, BaO, ZnO, $Al_2O_3$, $La_2O_3$, $In_2O_3$, $SiO_2$, $TiO_2$, $ZrO_2$, $GeO_2$, $SnO_2$, $Nb_2O_5$, $Ta_2O_5$, or $ThO_2$, "D" is vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), or nickel (Ni). The numbers in the noted formula are the following: "z" is 0 to 1, "u" is from 0 to 1,

30     "y" is from $1 \times 10^{-4}$ to 0.1, "e" is form 0 to 1, and "t" is from 0 to 0.01. These

definitions apply wherever they are found in this application unless specifically stated to the contrary. It is also contemplated that "M", "X", "A", and "D" represent multiple elements in the groups identified above.

The fluorescent intensifying screens useful in this invention exhibit
5 a photographic speed of at least 600. The preferred phosphor is a terbium activated gadolinium oxysulfide. Moreover, the coverage of phosphor in the dried layer is from about 12 to about 15 $g/dm^2$ on one side of the support and from about 4 to about 6 $g/dm^2$ on the other side. The phosphor to binder weight ratio is from about 20:1 to about 22:1 on each side of the support.

10 Flexible support materials for radiographic screens in accordance with the present invention include cardboard, plastic films such as films of cellulose acetate, polyvinyl chloride, polyvinyl acetate, polyacrylonitrile, polystyrene, polyester, polyethylene terephthalate, polyamide, polyimide, cellulose triacetate and polycarbonate, metal sheets such as aluminum foil and aluminum
15 alloy foil, ordinary papers, baryta paper, resin-coated papers, pigmented papers containing titanium dioxide or the like, and papers sized with polyvinyl alcohol or the like. A plastic film is preferably employed as the support material.

The plastic film may contain a light-absorbing material such as carbon black, or may contain a light-reflecting material such as titanium dioxide or
20 barium sulfate. The former is appropriate for preparing a high-resolution type radiographic screen, while the latter is appropriate for preparing a high-sensitivity type radiographic screen. For use in this invention it is highly preferred that the support absorb substantially all of the radiation emitted by the phosphor. Examples of particularly preferred supports include polyethylene terephthalate,
25 blue colored or black colored (for example, LUMIRROR C, type X30 supplied by Toray Industries, Tokyo, Japan). These supports may have a thickness that may differ depending o the material of the support, and may generally be between 60 and 1000 μm, more preferably between 80 and 500 μm from the standpoint of handling.

A representative fluorescent intensifying screen useful in the present invention is described as Screen Y in the Example below. This screen can be prepared using components and procedures known by one skilled in the art.

5  **Imaging and Processing**

Exposure and processing of the radiographic silver halide films of this invention can be undertaken in any convenient conventional manner. The exposure and processing techniques of U.S. Patents 5,021,327 and 5,576,156 (both noted above) are typical for processing radiographic films. Other processing

10  compositions (both developing and fixing compositions) are described in U.S. Patent 5,738,979 (Fitterman et al.), U.S. Patent 5,866,309 (Fitterman et al.), U.S. Patent 5,871,890 (Fitterman et al.), U.S. Patent 5,935,770 (Fitterman et al.), U.S. Patent 5,942,378 (Fitterman et al.), all incorporated herein by reference. The processing compositions can be supplied as single- or multi-part formulations, and

15  in concentrated form or as more diluted working strength solutions.

Exposing X-radiation is generally directed through a patient and then through a fluorescent intensifying screen arranged against the frontside of the film before it passes through the radiographic silver halide film, and the second fluorescent intensifying screen.

20  It is particularly desirable that the radiographic silver halide films of this invention be processed within 90 seconds ("dry-to-dry") and preferably for at least 20 seconds and up to 60 seconds ("dry-to-dry"), including the developing, fixing, any washing (or rinsing) steps, and drying. Such processing can be carried out in any suitable processing equipment including but not limited to, a Kodak X-

25  OMAT® RA 480 processor that can utilize Kodak Rapid Access processing chemistry. Other "rapid access processors" are described for example in U.S. Patent 3,545,971 (Barnes et al.) and EP 0 248,390A1 (Akio et al.). Preferably, the black-and-white developing compositions used during processing are free of any photographic film hardeners, such as glutaraldehyde.

30  Radiographic kits can include a radiographic silver halide film or imaging assembly of this invention, one or more additional fluorescent

intensifying screens and/or metal screens, and/or one or more suitable processing compositions (for example black-and-white developing and fixing compositions).

The following examples are presented for illustration and the invention is not to be interpreted as limited thereby.

5

**Example 1:**

Radiographic Film A (Control):

Radiographic Film A was a dual-coated film having the two different silver halide emulsion layers on each side of a blue-tinted 170 μm

10 transparent poly(ethylene terephthalate) film support and an interlayer and overcoat layer over each emulsion layer. The emulsions of Film A were not prepared using oxidized gelatin.

Radiographic Film A had the following layer arrangement:

Overcoat

15               Interlayer

Emulsion Layer

Support

Emulsion Layer

Interlayer

20               Overcoat


The noted layers were prepared from the following formulations.

| Overcoat Formulation | Coverage $(mg/dm^2)$ |
|---|---|
| Gelatin vehicle | 3.4 |
| Methyl methacrylate matte beads | 0.14 |
| Carboxymethyl casein | 0.57 |
| Colloidal silica (LUDOX AM) | 0.57 |
| Polyacrylamide | 0.57 |
| Chrome alum | 0.025 |
| Resorcinol | 0.058 |
| Spermafol | 0.15 |

(Row numbers in left margin: 25 aligns with Gelatin vehicle; 30 aligns with Chrome alum)

| Interlayer Formulation | Coverage (mg/dm$^2$) |
|---|---|
| Gelatin vehicle | 3.4 |
| Carboxymethyl casein | 0.57 |
| Colloidal silica (LUDOX AM) | 0.57 |
| Polyacrylamide | 0.57 |
| Chrome alum | 0.025 |
| Resorcinol | 0.058 |
| Nitron | 0.044 |

| Emulsion Layer Formulation | Coverage (mg/dm$^2$) |
|---|---|
| Tabular grain emulsion [AgBr 2.9 μm ave. dia. x 0.10 μm thickness] | 16.1 |
| Gelatin vehicle | 26.3 |
| 4-Hydroxy-6-methyl-1,3,3a,7-tetraazaindene | 2.1 g/Ag mole |
| Potassium nitrate | 1.8 |
| Ammonium hexachloropalladate | 0.0022 |
| Maleic acid hydrazide | 0.0087 |
| Sorbitol | 0.53 |
| Glycerin | 0.57 |
| Potassium bromide | 0.14 |
| Resorcinol | 0.44 |
| Bisvinylsulfonylmethane | 2% based on total gelatin in all layers on each side |

Radiographic Film B (Control)

Film B was like Film A except that the tabular silver halide grains in the emulsion layers had an average size of 2.9 x 0.12 μm and were coated at a coverage of 18.3 mg/dm$^2$.

Radiographic Film C (Invention):

Radiographic Film C was a dual-coated, symmetric radiographic film with the same silver halide emulsion layer on each side of the support. The two emulsion layers contained tabular silver halide grains that were prepared and dispersed in deionized oxidized gelatin that had been added at multiple times before and/or during the nucleation and early growth of the silver bromide tabular grains dispersed therein. The tabular grains of each silver halide emulsion layer had a mean aspect ratio of about 40. The nucleation and early growth of the tabular grains were performed using a "bromide-ion-concentration free-fall" process in which a dilute silver nitrate solution was slowly added to a bromide ion-rich deionized oxidized gelatin environment. The grains were chemically sensitized with sulfur, gold, and selenium using conventional procedures. Spectral sensitization to about 560 nm was provided using anhydro-5,5-dichloro-9-ethyl-3,3'-bis(3-sulfopropyl)oxacarbocyanine hydroxide (680 mg/mole of silver) followed by potassium iodide (400 mg/mole of silver).

Film C had the following layer arrangement and formulations on the film support:

Overcoat
Interlayer
Emulsion Layer
Support
Emulsion Layer
Interlayer
Overcoat

| Overcoat Formulation | Coverage (mg/dm$^2$) |
|---|---|
| Gelatin vehicle | 3.4 |
| Methyl methacrylate matte beads | 0.14 |
| Carboxymethyl casein | 0.57 |
| Colloidal silica (LUDOX AM) | 0.57 |
| Polyacrylamide | 0.57 |

| | | |
|---|---|---|
| Chrome alum | | 0.025 |
| Resorcinol | | 0.058 |
| Spermafol | | 0.15 |

5

| Interlayer Formulation | Coverage (mg/dm$^2$) |
|---|---|
| Gelatin vehicle | 3.4 |
| Carboxymethyl casein | 0.57 |
| Colloidal silica (LUDOX AM) | 0.57 |
| Polyacrylamide | 0.57 |
| Chrome alum | 0.025 |
| Resorcinol | 0.058 |
| Nitron | 0.044 |

10 (Chrome alum row)

| Emulsion Layer Formulation | Coverage (mg/dm$^2$) |
|---|---|
| Tabular grain emulsion [AgBr 4.0 μm ave. dia. x 0.10 μm thickness] | 19.4 |
| Oxidized gelatin vehicle | 3 |
| Non-oxidized gelatin vehicle | 23.3 |
| 4-Hydroxy-6-methyl-1,3,3a,7-tetraazaindene | 2.1 g/Ag mole |
| Potassium nitrate | 1.8 |
| Ammonium hexachloropalladate | 0.0022 |
| Maleic acid hydrazide | 0.0087 |
| Sorbitol | 0.53 |
| Glycerin | 0.57 |
| Potassium bromide | 0.14 |
| Resorcinol | 0.44 |
| Bisvinylsulfonylmethane | 2.0 % based on total gelatin on each side |

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The cassettes used for imaging contained two of the following screens, one on each side of the noted radiographic films:

Fluorescent intensifying screen "X" was a commercially available KODAK Lanex® Regular Screen. It comprised a terbium activated gadolinium oxysulfide phosphor (median particle size of 7.8 to 8 μm) dispersed in a Permuthane™ polyurethane binder on a white-pigmented poly(ethylene

5      terephthalate) film support. The total phosphor coverage was 4.83 g/dm$^2$ and the phosphor to binder weight ratio was 19:1.

Fluorescent intensifying screen "Y" was a commercially available Kodak Lanex® Fast Screen. It comprised two terbium activated gadolinium oxysulfide phosphor layers on opposing sides of a white-pigmented poly(ethylene

10     terephthalate) film support. The phosphor in each layer (median particle size of 7.8 to 8 μm) was dispersed in a Permuthane™ polyurethane binder. The total phosphor coverage on one side ("exposed side") was 4.83 g/dm$^2$ and the total phosphor coverage on the opposite side ("back side") was 13.5 g/dm$^2$. The phosphor to binder weight ratio for each phosphor layer was 19:1.

15     Samples of the films in the imaging assemblies were exposed using an inverse square X-ray sensitometer (device that makes exceedingly reproducible X-ray exposures). A lead screw moved the detector between exposures. By use of the inverse square law, distances were selected that produced exposures that differed by 0.100 LogE. The length of the exposures was constant. This

20     instrument provided sensitometry that gives the response of the detector to an imagewise exposure where all of the image is exposed for the same length of time, but the intensity is changed due to the anatomy transmitting more or less of the X-radiation flux.

The exposed film samples were processed using a commercially

25     available KODAK RP X-OMAT® Film Processor M6A-N, M6B, or M35A. Development was carried out using the following black-and-white developing composition:

|  |  |  |
|---|---|---|
| | Hydroquinone | 30 g |
| 30 | Phenidone | 1.5 g |
| | Potassium hydroxide | 21 g |

| NaHCO$_3$ | 7.5 g |
| K$_2$SO$_3$ | 44.2 g |
| Na$_2$S$_2$O$_5$ | 12.6 g |
| Sodium bromide | 35 g |
| 5-Methylbenzotriazole | 0.06 g |
| Glutaraldehyde | 4.9 g |
| Water to 1 liter, pH 10 | |

Fixing was carried out using KODAK RP X-OMAT® LO Fixer and Replenisher fixing composition (Eastman Kodak Company). The film samples were processed in each instance for less than 90 seconds ("dry-to-dry").

Optical densities are expressed below in terms of diffuse density as measured by a conventional X-rite Model 310TM densitometer that was calibrated to ANSI standard PH 2.19 and was traceable to a National Bureau of Standards calibration step tablet. The characteristic density vs. log E curve was plotted for each radiographic film that was exposed and processed as noted above. System speed was measured as noted above. Contrast (gamma) is the slope (derivative) of the density vs. logE sensitometric curve. SSM data for the screens were determined as described above. Only the SSM values at 2 cycles/mm are reported in TABLE II but FIG. 4 shows the SSM data over the entire range of spatial frequencies for Screen Y in an imaging assembly of the present invention.

The following TABLE II shows that increased system speed can be achieved by using either larger tabular silver halide grains (Film B) or "faster" screens (Screen Y). However, the use of larger tabular silver halide grains result in higher fog (D$_{min}$) and the use of a "faster" screen results in a lower SSM value. The present invention provides extremely high system speed (Film C with Screen Y) without increased fog. The images obtained using the present invention had excellent contrast in comparison to the imaging assembly comprised of Film A and Screen Y.

TABLE II

| Film | Tabular grain size (μm) | Screen | Contrast | Fog (D_min) | System Speed | Film Speed | SSM @ 2 cycles/mm |
|---|---|---|---|---|---|---|---|
| A (Control) | 2.9 x 0.10 | X | 2.9 | 0.27 | 400 | 400 | 0.49 |
| A (Control) | 2.9 x 0.10 | Y | 2.9 | 0.27 | 559 | 400 | 0.24 |
| B (Control) | 2.9 x 0.12 | X | 2.9 | 0.3 | 620 | 600 | 0.49 |
| B (Control) | 2.9 x 0.12 | Y | 2.9 | 0.3 | 865 | 600 | 0.24 |
| C (Control) | 4.0 x 0.10 | X | 3.2 | 0.25 | 1007 | 1000 | 0.49 |
| C (Invention) | 4.0 x 0.10 | Y | 3.2 | 0.25 | 1406 | 1000 | 0.24 |

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

## Parts List

| 10 | slit-shaped X-ray |
|----|-------------------|
| 15 | phosphor screen sample |
| 20 | optical slit |
| 25 | X-ray slit or mask |
| 30 | photomultiplier tube (PMT) |
| 35 | integrating sphere |
| 45 | profile or spread |